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Research and Development Technical Report
ECOM 02135-F

DEVELOPMENT OF MAGNESIUM WAFER CELLS

Final Report

by

LLOYD W. EATON

December 1968

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UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

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BURGESS BATTERY COMPANY
DIVISION OF SERVEL, INC.
FREEPORT, ILLINOIS 61032

68

TECHNICAL REPORT ECOM 02135-F

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DEVELOPMENT OF MAGNESIUM WAFER CELLS

Final Report
Period Covered
31 October 1967 to 30 April 1968

Contract No. DA28-043 AMC 02135 (E)
DA Project No. IT6-22001-A-53, Task 02, Subtask 38

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Abstract

Contract No. Da28 043 AMC 02135 (E)

The principal physical condition causing constructional difficulties in both the 1-3/4 X 3-1/4 inch and 1-1/8 X 1-1/8 inch cell size batteries was the evolution of gas during storage and discharge. A revision in seal construction and moisture barrier size reduced the failure rate, particularly on the 1-1/8 X 1-1/8 inch cell size.

A protective coating to prevent corrosion of the non-reactive side of the anode is necessary to prevent corrosion of the electrical contact area of the anode.

A magnesium wafer battery cannot be contained within a specified dimension due to expansion of discharge products. Provision must be allowed for this expansion in battery design. Special measures to contain the expansion reduces the capacity of the battery.

It should be possible to build a 1-1/8 X 1-1/8 inch cell size battery with a 90% survival rate when stored one month at 160°F.

The Impedance-Phase Angle measurements, particularly phase angle, on complete wafer batteries is a potentially useful method of determining the condition of a battery in a non-destructive manner.

Publications, Lectures, Reports and Conferences

Publications: None

Reports: None

Lectures: None

Conferences:

1. 14 March 1968, outlined progress to date and discussed contract completion requirements. Held at ECOM, Fort Monmouth, New Jersey. Attended by Donald B. Wood of the U. S. Army Electronics Command and Howard J. Strauss and Lloyd W. Eaton of Burgess.

Cell and Battery Construction

The objectives proposed in the Semi-Annual Report ECOM 02135-5 were as follows:

1. Verify the theory that the contact area protection from moisture requires complete protection of the non-active side of magnesium anode.

2. Determine the most effective material for providing the corrosion protection of the non-reactive side of the magnesium anode.

3. Verify the supposed destructive effect of perchlorate on rubber hydrochloride cell wrap.

4. Qualify PZ2000.21 (Dow) film as a cell wrap material for perchlorate mix cells.

5. Qualify polyethylene coated paper as a cell wrap material for perchlorate mix cells.

6. Test seamed cans for the 1-1/8" X 1-1/8" size batteries, as full F_1 sections of the Ba4270/U, for containment of the cell expansion.

7. Devise a wax proof gas leak device, i.e. one that does not plug with wax during potting, for 1-1/8" X 1-1/8" size battery to relieve the hydrogen gas, produced on discharge, that is contained by the sealing in a fresh battery.

8. Test methods of redistributing expansion forces in the Ba-4386/PRC-25 flat cell battery employing a cell measuring 1-3/4" X 3-1/4" to allow containment of the battery within the design limits.

9. Assuming perchlorate battery cell wrap problems are overcome and a surviving battery co[illegible] made, determine the delay characteristics of voltage build-up.

10. Test batteries stored at 145°F.

Moisture Protection of Contact Area

It was found that if any bare metal exists on the non-active side relative to the cell of the magnesium anode corrosion will start at this bare section and proceed under all protective materials surrounding the contact area, producing variable corrosion of the contact area and this in turn results in slight resistance increase to an effectively open circuit.

The following materials and methods were tried to protect the contact area:

1. H. B. Fuller Co. HM 113R hot melt adhesive smeared over entire non-active side of anode except 1/4 inch diameter contact area.
2. National Starch 34-3104 hot melt adhesive applied in the same manner.
3. Coast-to-Coast Spray Paint of the following code numbers without a primer coat.
   a. GPO-224-8
   b. GP-207
   c. GP-214
   d. GP-206
   e. GP-205
4. Primer spray paint used with GP-205 and GPO-224-8 spray paints
   a. Coast-to-Coast GP-234
   b. Coast-to-Coast GP-230
   c. Tempo Products Co. No. E-2000 spray primer

The materials were tested by making complete battery units, storing for one month at 160°F., discharging, and examination. The relative results of these anode protective coatings would be:

1. H. B. Fuller Co. HM113R hot melt -- poor
2. National Starch 34-3104 hot melt -- good, if applied carefully
3. Coast-to-Coast spray paint

a.	GPO-224-8	good
b.	GP-207	fair, minus
c.	GP-214	poor
d.	GP-206	fair, plus
e.	Gp-205	good

4. Primer spray paint with GP-205 and GPO-224-8 spray paints

a.	Coast-to-Coast GP-234	very poor
b.	Coast-to-Coast GP-230	good
c.	Tempo Products Co. No. 3-2000	fair, minus

The effectiveness of the paint coating is affected by the pickling process employed on the magnesium and further work is needed to obtain a uniformly effective coating that is easy to apply. The nature of the pigment in the paint also affects the ability of the coating to survive as a protective coating.

The percentage of pigment in the paint and the percentile composition of the pigment of the various paints employed are as follows:

GPO-224-8

Pigment per centage in paint	3.77%
Titanium Dioxide	40.1 %
Chrome Yellow	48.9 %
Yellow Iron Oxide	9.9 %
Brown Iron Oxide	0.7 %
Red Iron Oxide	0.4 %

GP-207

Pigment per centage in paint	1.72%
Titanium Dioxide	32.5 %
Iron Blue	67.5 %

GP-214

Pigment per centage in paint	1.40%
Toluidine Red	100. %

GP-206

Pigment per centage in paint	3.02%
C. P. Chrome Yellow	54.5 %
C. P. Chrome Yellow Med.	9.1 %
Titanium Dioxide	36.4 %

GP-205

Pigment per centage in paint	2.10%
Chrome Yellow Lemon	46.0 %
Chrome Green Med.	54.0 %

The Toluidine Red (GP-214) was altered chemically in the cell during 160°F. storage and corrosion was generalized.

The Iron Blue (GP-207) would be altered chemically but the effect would be variable from total failure to isolated spots on a few cells.

The pigment in GP-206 was not altered chemically but the coating tended to be porous and would "lift" from the anode and allow corrosion in variable degrees.

Effect of Perchlorate on Rubber Hydrochloride Film

BA-4386 units were made using 5N perchlorate wetter in the cathode mix and rubber hydrochloride cell wrap. Units were stored one month at 160°F. and one and three months at 130°F. Careful dismantling of the units was performed and the individual cells examined under a microscope at 16X. Small holes were found just inside the heat sealed area of the 130°F. samples. The holes were found to have joined to form a slit-like opening in the 160°F. samples that could almost be seen with the unaided eye. These openings allowed electrolyte to escape, causing massive destruction within the battery. Apparently the heat of sealing partially degraded the adjacent rubber hydrochloride film so that the perchlorate could attack the area. The unheated parts of the cell wrap apparently were not affected by the perchlorate to a detectable degree.

Qualification of PZ2000.21 (Dow) Film

This material has been found to be inert to the effect of perchlorate but suffers mechanical difficulties in obtaining an effective heat seal.

Heat sealing produced false seals and hidden extrusion-like holes that were very difficult to find even under 16X observation. Because of this characteristic the material, by itself, is unsatisfactory, but modification as a laminate with other film materials holds promise. A number of battery units were made and are discussed in other sections of this report.

Qualification of Polyethylene Coated Paper

This material is not practical in the cell assembly employed. The heat of sealing damages the continuity of the polyethylene film in the areas adjacent to the seal. The other non-heat affected areas survive one month at 160°F. in excellent condition. The leakage allowed by this heat seal damage causes massive destruction within the battery.

Seamed Cans for 1-1/8 X 1-1/8 Inch Cell Size Batteries

The rolled seam, shown as Fig. 4 in appendix and used on both 1-1/8 X 1-1/8 and 1-3/8 X 3-1/4 inch cell size cans, would hold approximately 50% of the time on 1-1/8 X 1-1/8 cell size batteries. It cannot be relied upon to contain the batteries within the can due to the expansive pressure of the discharge products. The seamed cans were also edge welded to insure containment on most units.

Gas Leak Device

It was found that the gas produced on discharge is not escaping the individual cells as thought and being trapped in the wax coated battery

can but is actually being held within the individual cells with the can restraining the ballooned cell wrap. To be effective, each cell would require a gas leak device. It was found that as long as the discharge rate did not exceed 0.028 amp/sq. inch, on a continuous basis, the electrical contact between cells could be maintained by adjusting the degree of compression.

Containment of Ba-4386 Battery

It was found to be impossible to contain a unit within the specified design limits. The most successful method found in restricting the expansion was to weld 1/4 X 1/8 inch steel bars across the ends of the battery can, two bars per end equally spaced. Seven units were made in this manner. Three suffered some heat damage due to the welding and shorted. The resultant gas pressure caused the can seam to yield and the cell wrap exploded. Three, on discharge, ruptured the welds or tore the metal of the can. Only one was totally restricted. The capacities of the restricted units is noticeably less than the equivalent unit in which the only restriction is the can cover itself. It would appear that to operate properly magnesium flat cell batteries must be allowed a degree of restrained expansion. Too much expansion room, i.e. addition of fibrous material or balsa wood, or too little per above experiment reduces the capacity. A possible explanation is the physical nature of the discharge product on the anode. If too much room is allowed this product is bulky and voluminous and causes too much separation in the cell increasing cell

resistance. In excessively restrained units this product becomes hard and compressed, preventing easy access of electrolyte to the anode metal, again increasing resistance. An example of this effect is shown in the A_2 sections of fresh Ba-4386 batteries using perchlorate mix.

	Capacity in hours to 10.0 volts/9.0 volts	
	Unit 1	Unit 2
Standard can construction	71.5/74.1	72.5/78.3
Restrictive bars	56.9/65.5	56.8/64.5
Fibrous pad	57.9/60.0	33.3/33.4

The use of 1/4 inch thick sponge rubber provided such eash expansion that the gas evolution or discharge separated the current collector from the cathode, causing an open circuit to appear shortly after placing the battery on discharge.

Cell Integrity

The dominant mode of failure in both the 1-3/4 X 3-1/4 inch and 1-1/8 X 1-1/8 inch cell sizes was a degree of shorting of physical destruction due to the presence of free electrolyte outside the cells. With the exception of the PZ-2000.21 a film poor seal performance was inadequate to account for the persistent appearance of this electrolyte so microscopic examination of the 160°F. stored units was undertaken to try to trace the source of this leakage. The effect of this leakage on the 1-3/4 X 3-1/4 inch cell size batteries was much more severe than the effect on the 1-1/8 X 1-1/8 inch cell size batteries and perchlorate units

suffered more than bromide units.

An indication of the difference in severity of damage between the bromide and perchlorate units, with the construction described in ECOM 02135-5 and shown in Figs. 1, 2, and 3 of this report, i.e. hot melt ring seals and anode size moisture barriers, is shown in Table I (bromide 1-1/8 X 1-1/8 cell size) and Table V (perchlorate 1-1/8 X 1-1/8 cell size.)

The first change to improve this performance was to reduce the size of the moisture barrier to 19/32 inch diameter. The effectiveness of this change is shown in Table II (bromide) and Table VI (perchlorate) as compared to Tables I and V.

Microscopic examination of the units in Tables I, II, V, and VI (1-1/8 X 1-1/8 cell size) and Tables IX, X, XIII, and XIV (1-3/4 X 3-1/4 cell size) eventually produced a consensus as to the primary source of this leakage. It appears that the plasticizer present in the cathode current collector material migrates, at 160°F., into the hot melt ring seal between the collector and cell wrap. This alteration of the seal and the pressure of the gas produced on storage would force the seal allowing some electrolyte to escape during storage damaging the batteries. Further electrolyte is forced out of the now porous seal by the gas pressure generated during discharge adding to the damage.

The second change in cell construction was the replacement of the hot melt ring seal between the cathode current collector and cell wrap with 3-M Company's No. 666 adhesive tape the same size as the cathode current collector. Holes were provided for contact to the current collector. The effect of this change on the 1-1/8 X 1-1/8 cell size units is shown

as Series 1 and 2 of Table III (bromide.)

This change totally stopped the leakage occurring at the cathode current collector seal but caused an increase in failure rate on discharge due to disconnection of the current collector in one or more cells by the pressure of the gas generated on discharge. The ring seals had, apparently, provided a form of gas leak. The compression was increased by either cutting the battery can down in size or increasing the cathode mix content approximately 4.5%. This effect is shown in Table III, series 3-6, Tables VII, VIII (1-1/8 X 1-1/8 cell size) and Tables XI and XV (1-3/4 X 3-1/4 cell size.)

Corrosion of the anode contact reappeared in the units employing the tape seal between the cathode current collector and cell wrap. Careful examination of cells from these units indicated that the hot melt ring seal between the anode and cell wrap was now being forced by the increased gas pressure, during storage at 160°F., due to seal improvement on the collector. This effect was largely confined to the 1-3/4 X 3-1/4 cell size. The 1-1/8 X 1-1/8 cell size apparently did not produce enough gas on storage to cause this damage to any degree.

The third change in cell construction was to replace the ring seal on the painted anode with a 1 X 1 inch piece of No. 666 tape. This tape seal between the cell wrap and anode and current collector totally stopped leakage at these points. Any leakage found in these units resulted from true heat seal failure of the cell wrap. Units made in this manner are listed in Tables IV and VIII (1-1/8 X 1-1/8 cell size) and Tables XII and

XVI (1-3/4 X 3-1/4 cell size.)

Phase Angle and Impedance

Very late in the contract period a Hewlett-Packard Vector Impedance Meter Model 4800A was obtained to study the phase angle and impedance characteristics of the Ba-4386 units, the purpose being to determine the condition of the battery before and after storage by non-destructive means. Although the data is limited, the results are favorable and indicate that the impedance-phase angle measurements, and particularly the phase angle, can be correlated, to a degree, with various conditions within a battery.

As noted in earlier sections of this report, leakage of electrolyte was the singular most serious source of failure and a non-destructive means of detecting this leakage and locating the source was one of the prime objectives of this work.

The data, indeed, did point to a common characteristic for batteries with leakage that separated them from normal units. This characteristic is a marked downward deviation of the phase angle from tolerance limits established for normal units without leakage. The tolerance limits were determined by the pragmatic method of measuring a number of units. All fresh units showing this deviation destroyed themselves during storage at 160°F. The impedance measurements seemed to have intuitive value but were difficult to tie in specifically to any particular condition. There appeared to be some correlation of the impedance to electrical contact between cells and dryness of the cathode.

The phase angle of units, after storage one month at 160°F., showed deviation from the fresh state when leakage occurred during storage. Units that show little or no deviation from the fresh norm could be expected to perform properly. Units with deviation ran poorly compared to non-deviant units.

The impedance increased generally after storage more so at the lower frequencies. Bromide electrolyte battery impedances were generally higher than perchlorate electrolyte batteries. Severe impedance increase after storage with little phase angle deviation usually indicated corrosion of the electrical contacts on the anode.

The Hewlett-Packard Model 4800A Vector Impedance Meter is provided with a direct measurement plug-in that allows an external circuit that is to be measured to be applied directly to the instrument and phase angle, impedance, resistance and capacitance or inductance can be read directly on meters incorporated in the instrument. The frequency is adjustable over 5 HZ to 500 KH_Z in five bands. Frequencies beyond 10 KH_Z were of no value in this work. The nature of the instrument is such that the DC voltage of the battery must be blocked so a 20,000 MFD capacitor was interposed between the test batteries and instrument. The impedance of this capacitor is of no consequence in the readings. There is a phase angle shift resulting from this capacitor, but it is essentially constant over the range and does not seem to affect the interpretations of the battery results. The instrument is such that the frequency can be swept by an external oscillator over a given decade and the impedance and phase angle, through an analog output that is provided, read out

on an oscilloscope and the trace photographed. Due to the application being a little unusual for the equipment, some difficulty was experienced in its operation and adjustment and a modification of the meter was required. This limited its use during the contract period to manual adjustment of the frequency and the period of time available for measurements was too short for extensive data.

The meter supplies a test signal to the unknown circuit less than 2.2 millivolts RMS in the range employed. The current of the injected signal is held constant by the meter's circuitry and the impedance is directly proportional to the voltage. The phase angle is determined within the meter by circuitry that compares the signals from the voltage and current channels.

The fresh bromide mix units of Series 5, Table XI and Series 2, Table XII were measured for impedance and phase angle at various frequencies. The phase angle characteristic of the series is represented by the following average values with the tolerance deviation spread including every unit measured except Unit #1 of Series 5, Table XI.

A_2 Section

Frequency - Hz	Average Phase Angle	Tolerance Plus	Tolerance Minus
30	77°	2°	2°
40	75	3	3
60	72	5	5
80	69	7	4
100	67	6	4
200	60	8	6
400	50	10	8
600	42	10	9
800	37	10	8
1K	33	9	6
2K	24	8	6
5K	13	6	4

A_1 Section

Frequency - Hz	Average Phase Angle	Plus	Minus
30	75°	5°	3°
40	74	4	5
60	69	6	4
80	67	6	6
100	63	7	6
200	51	9	8
400	38	11	9
600	31	7	9
800	24	9	7
1K	21	7	6
2K	11	7	5
5K	Inductive	---	---

The A_2 section tolerance deviation spread of the fresh bromide units is shown in Figure 5 as two solid lines. The cross points represent the fresh phase angle value of the first battery of Series 5, Table XI. This unit was the only unit of the two series with a serious deviation outside the tolerance limit. The unit destroyed itself within one week when stored at 160°F. The deviation was caused by leakage of electrolyte. This unit did not show any variation from the norm in either voltage or current producing ability. The A_1 section values of the same units are plotted in Figure 6 with the cross point values of the above noted unit #1 of Series 5, Table XI. The leakage source would appear to be in the A_2 section.

The units of Series 5, Table XI were measured for impedance and phase angle after storage for one month at 160°F. Units 2, 4, 5, and 6 showed open circuit in the A_2 section. These units were opened and some leakage was found that had corroded the A_2 positive lead. This lead was replaced and the units recanned and discharged. Units 3, 7, 8, 9, and 10 A_2 section phase angle data is shown as cross points on Fig. 7. The two solid lines are the fresh deviation tolerance limits noted earlier. It will be noted that very little change occurred in the phase angle. Fig. 8 shows the same data for the A_1 section of these units. Also little deviation will be noted. The impedance data noted for the A_2 section in Fig. 9 shows a significant change had occurred. The two lines for fresh and after 160°F. storage encompass every unit of the series and are essentially maxima and minima points for the various frequencies. Examination of these units showed that the gas pressure, produced during storage and trapped by the cathode collector tape seal, had forced the hot melt smear seal, allowing

electrolyte to escape at the electrical contact point on the anode. Considerable corrosion of this contact was found and the free electrolyte had caused the A_2 positive lead to be destroyed or so close to being destroyed that further action on discharge completed the destruction of the lead.

The phase angle and impedance data for A_2 sections of units of series 1 Table 12 that were stored one month at 145°F. is shown in the same manner in Figs. 10 and 11. Due to equipment not being available at the time fresh data was not obtained on these units. The fresh phase angle data is assumed to be covered by the deviation limits described earlier in this report. The fresh impedance data is assumed to be equivalent to that of Series 2, Table XII. Acceptance of this fresh data limit indicates little deviation of phase angle and impedance occurred during storage and the units could be expected to discharge with reasonable capacity, which was the case.

The fresh perchlorate units of Series 8, Table 15 and Series 1 of Table 16 were also measured for impedance and phase angle with the following average values and tolerance limits.

A_2 Section

Frequency - Hz	Average Phase Angle	Tolerance Plus	Tolerance Minus
30	73°	2°	5°
40	72	2	2
60	69	3	1
80	68	1	2
100	66	2	1
200	61	1	2
400	53	1	1
600	47	3	3
800	42	4	3
1K	39	4	4
2K	29	6	4
5K	16	5	4

A_1 Section

Frequency - Hz	Average Phase Angle	Tolerance Plus	Tolerance Minus
30	74°	2°	1°
40	73	1	1
60	69	2	2
80	66	2	2
100	63	2	3
200	54	8	6
400	42	4	5
600	35	3	4
800	30	4	5
1K	26	3	5
2K	17	5	4
5K	Inductive	---	---

The tolerance deviation spread of A_2 and A_1 sections are shown as solid lines in Figs. 13 and 14. The cross point values are of a unit from Series 1, Table XV. This series failed due to leakage of electrolyte resulting from faulty PZ2000.21 heat seals. The voltages were normal and nothing appeared amiss at the time. The deviation in phase angle is severe in both the A_2 and A_1 sections. The impedance values of the fresh units did not show this deviation.

The perchlorate units of Series 1, Table 16 and Series 8, Table 15 were measured for impedance and phase angle after storage for one month at 160°F. The results of the phase angle measurements of the A_2 sections are shown as cross points in plots on Figures 15 and 16 respectively. The deviation from the fresh values is not great, indicating little or no leakage. This was substantiated on examination after discharge. The impedance limits of the A_2 sections of these units both fresh and after storage is shown in Figures 17 and 18. It will be seen from these plots an increase in impedance had occurred during storage. The units of Series 8, Table 15 (Fig. 18) experienced failure of the hot melt smear seal between the anode and cell wrap and a degree of corrosion was present on the contacts. Nothing could be found to account for the impedance shift of Series 1, Table 16 units. The most probable cause is a lack of electrolyte in the mix to carry the unit. The per centage of electrolyte had been reduced earlier in the project to ease physical problems in construction. The capacities of the units were fairly consistent and could be accounted for by electrolyte shortage.

CONCLUSIONS

1. The principal condition causing constructional difficulties was the evolution of gas during storage and on discharge.
2. Magnesium wafer batteries should not be restricted by extraordinary means to keep discharged unit within specifications. Room should be allowed for this expansion in the design.
3. The non-reactive side of the magnesium needs protection against corrosion in order to maintain a clean, conductive location for electrical contact.
4. A battery with 1-1/8 X 1-1/8 inch cell size can be made with reasonably consistent capabilities.
5. The phase angle and impedance of a battery at various frequencies probably is a useful way of characterizing the condition of a battery in a non-destructive manner.

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The code employed in Tables 1 - 16 to denote various constructional features is as follows:

Code Letter	Significance
A	Cell Wrap -- rubber hydrochloride
B	Cell Wrap -- polyethylene laminated paper
C	Cell Wrap -- Dow PZ2000.21 film
R	Anode Coating -- Fuller's HM-113 R smear
S	Anode Coating -- National Starch 34-3104 smear
T	Anode Coating -- Spray paint without primer
U	Anode coating -- Spray paint with primer

Table I

1-1/8 X 1-1/8 inch Cell Size: Hot Melt Ring Seals: Anode Size Moisture Seals
Magnesium Bromide Mix
Storage Condition: One month at 160°F.
Discharge: 24 cells on 2 min-18 min. Cyclic Load
1168 ohm/3214 ohm

Series	Cell Wrap Cathode	Cell Wrap Anode	Cathode Weight grams/cell	Anode Protective Coating	Capacity in Hours to 29.1 volts
	A	A	9	S	37.1
	A	A	9	S	29.8
1	A	A	9	S	29.3
	A	A	9	S	29.1
	A	A	9	S	29.1
	B	C	9	S	0
	B	C	9	S	0
2	B	C	9	S	0
	B	C	9	S	0
	B	C	9	S	0
	A	A	9	S	52.3
	A	A	9	S	52.1
3	A	A	9	S	48.6
	A	A	9	S	52.3
	A	A	9	S	53.3
	A	A	9	T	50.2
	A	A	9	T	52.6
4	A	A	9	T	49.7
	A	A	9	T	53.3
	A	A	9	T	50.8

Table II

1-1/8 X 1-1/8 inch Cell Size: Hot Melt Ring Seals: 19/32 inch Moisture Seals
Magnesium Bromide Mix
Storage Condition: One month at 160°F.
Discharge: 24 cells on 2 min.-18 min. cyclic load 1168 ohm/3214 ohm

Series	Cell Wrap	Cathode Weight grams/cell	Anode Protective Coating	Capacity in Hours to 29.1 volts
	A	9	T	46.1
	A	9	T	48.7
1	A	9	T	51.3
	A	9	T	51.0
	A	9	T	51.3
	A	9	T	31.4
	A	9	T	51.5
2	A	9	T	50.2
	A	9	T	51.5
	A	9	T	45.0

Table III

1-1/8 X 1-1/8 inch Cell Size: Tape cathode collector seal: 19/32 inch Moisture Seals
Magnesium Bromide Mix
Storage condition: one month at 160°F.

Series	Cell Wrap	Cathode Weight grams/cell	Anode Protective Coating	No. Cells, Load, End Point	Capacity
	A	9	T	X	49.4
	A	9	T	X	1.5
1	A	9	T	X	3.4
	A	9	T	X	1.0
	A	9	T	X	1.3
	A	9	T	X	36.7
	A	9	T	X	0
2	A	9	T	X	47.2
	A	9	T	X	46.7
	A	9	T	X	6.2
	A	9	T	XX	49.9
	A	9	T	XX	52.0
3	A	9	T	XX	52.3
	A	9	T	XX	52.7
	A	9	T	XX	0
	A	10	T	XX	47.7
	A	10	T	XX	49.3
4	A	10	T	XX	47.7
	A	10	T	XX	49.3
	A	9.5	T	XX	41.6
	A	9.5	T	XX	53.9
5	A	9.5	T	XX	28.3
	A	9.5	T	XX	28.3
	A	9.5	T	XX	55.2
	A	9.5	T	XX	32.3
	A	9.5	T	XX	32.3
6	A	9.5	T	XX	53.6
	A	9.5	T	XX	55.3
	A	9.5	T	XX	49.3

X -- 24 cells, 2 min.-18 min. cyclic load 1168 ohm/3214 ohm, end point 29.1 volts.

XX -- 28 cells, 2 min.-18 min. cyclic load 1363 ohm/3750 ohm, end point 34.0 volts.

Table IV

1-1/8 X 1-1/8 inch Cell Size: Tape seal cathode collector and anode;
19/32 inch Moisture Seals
Magnesium Bromide Mix
Storage Condition: One month at 160°F.
Discharge: 28 cells on 2 min.-18 min. Cyclic Load 1363 ohm/3750 ohm

Series	Cell Wrap	Cathode Weight grams/cell	Anode Protective Coating	Capacity in Hours to 34.0 volts
	A	9.5	U	50.7
	A	9.5	U	52.0
1	A	9.5	U	46.6
	A	9.5	U	52.2
	A	9.5	U	51.4
	A	9.5	U	49.4
	A	9.5	U	0
	A	9.5	U	0

Table V

1-1/8 X 1-1/8 inch Cell Size: Hot Melt Ring Seals: Anode Size Moisture Seals
Magnesium Perchlorate Mix
Storage Condition: One Month at 160°F.
Discharge: 24 Cells on 2 min.-18 min. Cyclic Load 1168 ohm/3214 ohm

Series	Cell Wrap Cathode	Cell Wrap Anode	Cathode Weight Grams/cell	Anode Protective Coating		Capacity in Hours to 29.1 Volts
	A	A	9	R		42.4
	A	A	9	R		9.0
1	A	A	9	R		27.9
	A	A	9	R		32.0
	A	A	9	R		38.3
	A	A	9	S		0
	A	A	9	S		0
2	A	A	9	S		0
	A	A	9	S		0
	A	A	9	S		32.3
	B	C	9	S	Fresh	36.6
	B	C	9	S		0
3	B	C	9	S		0
	B	C	9	S		0
	B	C	9	S		0
	B	C	9	R		0
	B	C	9	R		0
4	B	C	9	R		0
	B	C	9	R		0
	B	C	9	R		0
	B	C	9	T		0
	B	C	9	T		0
5	B	C	9	T		0
	B	C	9	T		0
	B	C	9	T		0
	C	C	9	T		0.6
	C	C	9	T		1.3
6	C	C	9	T		0
	C	C	9	T		1.3
	C	C	9	T		53.0

Table V (Cont.)

1-1/8 X 1-1/8 inch Cell Size: Hot Melt Ring Seals: Anode Size Moisture Seals
Magnesium Perchlorate Mix
Storage Condition: One Month at 160°F.
Discharge: 24 cells on 2 min.-18 min. Cyclic Load 1168 ohm/3214 ohm

Series	Cell Wrap Cathode	Cell Wrap Anode	Cathode Weight Grams/cell	Anode Protective Coating	Capacity in Hours to 29.1 volts
	C	C	9	S	0
	C	C	9	S	0
7	C	C	9	S	0
	C	C	9	S	0
	C	C	9	S	0
	C	C	9	T	40.8
	C	C	9	T	56.8
8	C	C	9	T	44.0
	C	C	9	T	0
	C	C	9	T	0

Table VI

1-1/8 X 1-1/8 inch Cell Size: Hot Melt Ring Seals: 19/32 inch Moisture Seals
Magnesium Perchlorate Mix
Storage Condition: One Month at 160°F.
Discharge: 24 cells on 2 Min.-18 Min. cyclic load 1168 ohm/3214 ohm

Series	Cell Wrap	Cathode Weight grams/cell	Anode Protective Coating	Capacity in Hours to 29.1 volts
	C	9	T	44.9
	C	9	T	45.3
1	C	9	T	41.6
	C	9	T	41.9
	C	9	T	35.5
	C	9	T	47.7
	C	9	T	43.4
2	C	9	T	1.3
	C	9	T	1.2
	C	9	T	33.1

Table VII
1-1/8 X 1-1/8 inch Cell Size: Tape Cathode Collector Seal:
19/32 inch Moisture Seals
Magnesium Perchlorate Mix
Storage Condition: One Month at 160°F.

Series	Cell Wrap	Cathode Weight grams/cell	Anode Protective Coating	No. Cells, Load, End-point	Capacity in Hours
	C	9	T	X	43.1
	C	9	T	X	43.3
1	C	9	T	X	0
	C	9	T	X	43.3
	C	9	T	X	43.5
	C	9	T	X	0
	C	9	T	X	7.3
2 *	C	9	T	X	0
	C	9	T	X	0
	C	9	T	X	0
	C	9	T	XX	47.3
	C	9	T	XX	31.3
3	C	9	T	XX	40.4
	C	9	T	XX	35.8
	C	9	T	XX	0.3
	C	9	T	XX	34.0
	C	9	T	XX	0
4	C	9	T	XX	0
	C	9	T	XX	0
	C	9	T	XX	0
	C	9.5	T	XX	24.4
	C	9.5	T	XX	0
5	C	9.5	T	XX	28.9
	C	9.5	T	XX	13.3
	C	9.5	T	XX	32.9

X -- 24 cells, 2 min-18 min. cyclic load 1168 ohm/3214 ohm, End point 29.1 volts.

XX -- 28 cells, 2 min.-18 min. cyclic load 1363 ohm/3750 ohm, End point 34.0 volts.

* 1 Mon. @ 145°F.

Table VIII

1-1/8 X 1-1/8 inch Cell Size: Tape Seal Cathode Collector and Anode:
19/32 inch Moisture Seals
Magnesium Perchlorate Mix
Storage Condition: One Month at 160°F.
Discharge: 28 cells, 2 min.-18 min. Cyclic Load 1363 ohm/3750 ohm

Series	Cell Wrap	Cathode Weight grams/cell	Anode Protective Coating	Capacity in Hours to 34.0 volts
	C	9.5	U	0
	C	9.5	U	0
1	C	9.5	U	0
	C	9.5	U	0
	C	9.5	U	0

A-11

Table IX

1-3/4 X 3-1/4 inch Cell Size: Hot Melt Ring Seals: Anode Size Moisture Seals
Magnesium Bromide Mix
65 grams/cell

Series	Cell Wrap	Anode Protective Coating	Storage Condition	Capacity A_2 10V/9V	Capacity A_1 2.12 V.
	A	R		0/0	25.7
	A	R		51.0/51.0	51.0
1	A	R	1 Mo. @ 160°F.	44.9/60.0	11.0
	A	R		55.8/75.0	45.4
	A	R		0/0	0
2	A	T	1 Mo. @ 130°F.	2.4/4.1	1.8
	A	T		62.7/71.7	100.3
	A	T		3.4/4.8	25.7
3	A	T	3 Mo. @ 130°F.	0.5/1.7	25.7
	A	T		0.0/0.5	0.5
	A	R		62.7/87.9	87.9
	A	R		62.2/83.0	72.0
4	A	R	1 Mo. @ 160°F.	58.0/78.9	58.4
	A	R		54.0/72.0	78.0
	A	R		65.0/83.2	79.7

A-11

Table X

19/32 inch Moisture Seals
See Table IX

	A	S	1 Mo. @ 145°F.	0/0	0
1	A	S		0/0	2.0
	A	S		0/0	0

Table XI

1-3/4 X 3-1/4 Size Cells: Tape Cathode Collector Seal: 19/32 inch Moisture Seals
Magnesium Bromide Mix
65 grams/cell

Series	Cell Wrap	Anode Protective Coating	Storage Conditions	Capacity A_2 10V/9V	Capacity A_1 2.12 V
1	C	T	1 Mo. @ 160°F.	0/0	0
	C	T		33.0/96.1	85.1
	A	T		0.3/1.1	0
	A	T		0/0	0
2	A	T	1 Mo. @ 160°F.	0/0	0
	A	T		4.3/17.0	0
	A	T		0.4/2.7	0
	A	T		39.2/68.1	55.0
	A	T		26.7/58.1	11.9
3	A	T	1 Mo. @ 160°F.	9.8/68.1	44.0
	A	T		72.3/79.3	90.0
	A	T		0/0	0
	A	T		0.4/1.6	0
	A	T		9.0/21.3	0
4	A	T	1 Mo. @ 160°F.	6.0/19.2	0.7
	A	T		7.4/59.0	1.5
	A	T		0/0	0
	A	S		0/0	0
	A	S		3.4/13.4	24.3
	A	S		24.3/44.4	2.2
	A	S		2.7/19.8	10.2
5	A	S	1 Mo. @ 160°F.	35.6/46.9	45.8
	A	S		0.5/1.4	18.3
	A	S		21.0/36.2	7.7
	A	S		2.4/7.6	3.4
	A	S		2.4/2.5	3.7
	A	S		2.8/3.6	33.3

Table XII

1-3/4 X 3-1/4 Size Cells: Tape Cathode Collector and Anode Seal: 19/32 inch Moisture Seals Magnesium Bromide Mix 65 grams/cell

Series	Cell Wrap	Anode Protective Coating	Storage Conditions	Capacity A_2 10V/9V	Capacity A_1 2.12V
	A	T		70.7/86.3	84.0
	A	T		57.3/70.7	25.9
1	A	T	1 Mo. @ 145°F.	58.5/80.3	51.7
	A	T		56.5/80.3	80.9
	A	T		63.4/80.3	57.1
	A	U		1.3/21.9	26.3
	A	U		20.7/55.4	6.1
2	A	U	1 Mo. @ 160°F.	31.6/53.6	31.7
	A	U		10.8/34.9	0
	A	U		8.7/29.7	0

Table XIII

1-3/4 X 3-1/4 inch Cell Size: Hot Melt Ring Seals: Anode Size Moisture Seals
Magnesium Perchlorate Mix
65 grams/cell

Series	Cell Wrap Cathode	Cell Wrap Anode	Anode Protective Coating	Storage Conditions	Capacity A_2 10V/9V	Capacity A_1 2.12 V.
1	B	C	R	1 Mo. @ 160°F.	0/0	0
	B	C	R		0/0	0
	B	C	R		0/0	0
	B	C	R		0/0	0
	B	C	R		0/0	0
2	A	A	S	1 Mo. @ 160°F.	0/0	0
	A	A	S		0/0	0
	A	A	S		0/0	0
	A	A	S		0/0	0
	A	A	S		0/0	0
3	A	A	R	1 Mo. @ 130°F.	0/0	0
	A	A	R		0/0	0
4	A	A	R	3 Mo. @ 130°F.	0/0	0
5	B	C	T	1 Mo. @ 160°F.	0/0	0
	B	C	T		0/0	0
	B	C	T		0/0	0
	B	C	T		0/0	0
	B	C	T		0/0	0
6	B	C	T	1 Mo. @ 160°F.	26.0/26.7	25.7
	B	C	T		33.4/37.0	32.0
	B	C	T		0/0	0
	B	C	T		0/0	0
	B	C	T		0/0	0
7	C	C	T	1 Mo. @ 160°F.	7.5	21.5
	C	C	T		11.4	19.0
	C	C	T		19.6	22.3
	C	C	T		0	0
	C	C	T		8.1	22.3
8	C	C	T	1 Mo. @ 160°F.	38.0/49.0	45.2
	C	C	T		5.8/7.4	51.3
	C	C	T		24.0/42.7	1.0
	C	C	T		35.6/49.2	44.8
	C	C	T		19.3/36.7	36.9

Table XIII (Cont.)

1-3/4 X 3-1/4 inch Cell Size: Hot Melt Ring Seals: Anode Size Moisture Seals
Magnesium Perchlorate Mix
65 grams/cell

Series	Cell Wrap Cathode	Cell Wrap Anode	Anode Protective Coating	Storage Condition	Capacity A_2 10V/9V	Capacity A_1 2.12 V
9	C	C	T	1 Mo. @ 160°F.	7.2/24.0	0
	C	C	T		31.3/50.6	52.0
	C	C	T		0/0	24.3
	C	C	T		0.2/0.5	0
10	C	C	T	1 Mo. @ 160°F.	21.7/36.0	50.3
	C	C	T		17.2/28.2	11.8
	C	C	T		0/0	0

Table XIV

1-3/4 X 3-1/4 inch Cell Size: Hot Melt Ring Seals: 19/32 inch Moisture Seals
Magnesium Perchlorate Mix
65 grams/cell

Series	Cell Wrap	Anode Protective Coating	Storage Conditions	Capacity A_2 10V/9V	Capacity A_1 10V/9V
	C	T		24.8/33.3	50.3
	C	T		24.0/31.4	33.4
1	C	T	1 Mo. @ 160°F.	0/0	0
	C	T		0/0	0
	C	T		0/0	0
	C	S		26.5/34.9	20.1
	C	S		32.8/40.3	44.0
2	C	S	1 Mo. @ 160°F.	28.3/28.3	44.0
	C	S		0/0	0
	C	S		0/0	0
	C	S		12.4/16.0	0.6
3	C	S	1 Mo. @ 160°F.	11.5/20.3	0
	C	S		8.0/8.0	8.0

Table XV

1-3/4 X 3-1/4 inch Size Cells: Tape Cathode Collector Seal
19/32 inch Moisture Seals
Magnesium Perchlorate Mix
65 grams/cell

Series	Cell Wrap	Anode Protective Coating	Storage Conditions	Capacity A_2 10V/9V	Capacity A_1 2.12 V
	C	T		0/0	0
	C	T		0/0	0
1	C	T	1 Mo. @ 160°F.	0/0	0
	C	T		0/0	0
	C	T		0/0	0
	C	T		19.0/30.0	35.9
	C	T		20.6/30.3	45.7
2	C	T	1 Mo. @ 160°F.	0/0	0
	C	T		0/0	0
	C	T		0/0	0
	C	T		5.0/21.0	0
	C	T		11.8/28.9	0
3	C	T	1 Mo. @ 145°F.	1.2/20.9	0.3
	C	T		13.0/31.3	26.2
	C	T		0/0	0
	C	T		0/0	0
	C	T		0/0	0
4	C	T	1 Mo. @ 160°F.	0/0	0
	C	T		0/0	0
	C	T		0/0	0
	C	T		5.5/9.2	26.7
	C	T		27.4/38.5	44.3
5	C	T	1 Mo. @ 160°F.	26.9/35.0	45.1
	C	T		0/0	0
	C	T		0/0	0
	C	T		48.0/70.6	71.3
	C	T		0/0	0
6	C	T	1 Mo. @ 145°F.	0/0	0
	C	T		0/0	0
	C	T		0/0	0

Table XV (Cont.)

1-3/4 X 3-1/4 inch Size Cells: Tape Cathode Collector Seal
19/32 inch Moisture Seals
Magnesium Perchlorate Mix
65 grams/cell

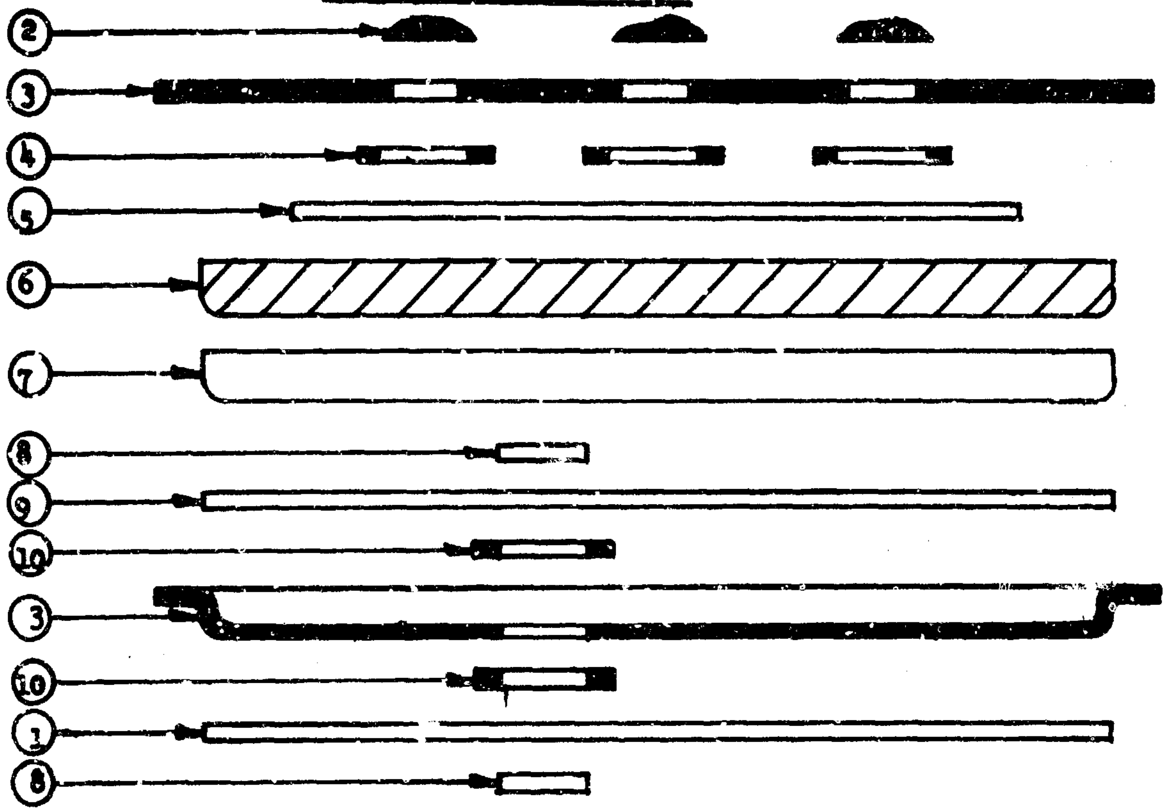
Series	Cell Wrap	Anode Protective Coating	Storage Conditions	Capacity A_2 10V/9V	Capacity A_1 2.12 V
	C	T		66.7/77.0	80.0
	C	T		74.1/80.0	84.3
7	C	T	48 hrs. @ 160°F.	74.2/80.0	96 0
	C	T		74.1/80.0	84.6
	C	T		0/0	0
	C	S		0/0	0
	C	S		11.2/26.1	14.5
8	C	S	1 Mo. @ 160°F.	26.3/49.7	49.7
	C	S		5.5/33.3	15.8
	C	S		25.3/27.8	17.5

Table XVI

1-3/4 X 3-1/4 inch Size Cells: Tape Cathode Collector and Anode Seals:
19/32 inch Moisture Seal
Magnesium Perchlorate Mix
65 grams/cell

Series	Cell Wrap	Anode Protective Coating	Storage Conditions	Capacity A_2 10V/9V	Capacity A_1 2.12 V
	C	U		29.3/41.2	48.0
	C	U		29.0/31.9	48.0
1	C	U	1 Mo. @ 160°F.	28.6/40.4	47.9
	C	U		27.7/32.8	7.3
	C	U		28.5/37.2	41.8

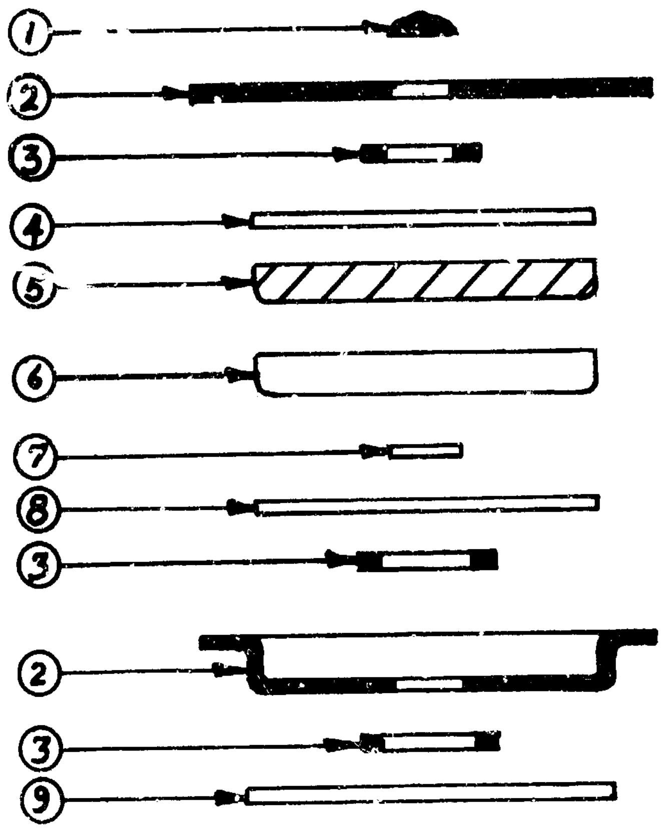
MAGNESIUM "P" WAFER CELL



1. Metallic Moisture Barrier
2. Inter-cell Connector
3. Cell Wrap
4. Adhesive Ring
5. Carbon Cloth
6. Cathode Mix
7. Separator
8. Nonpermeable Dot
9. Anode (Magnesium)
10. Adhesive Ring

Figure 1

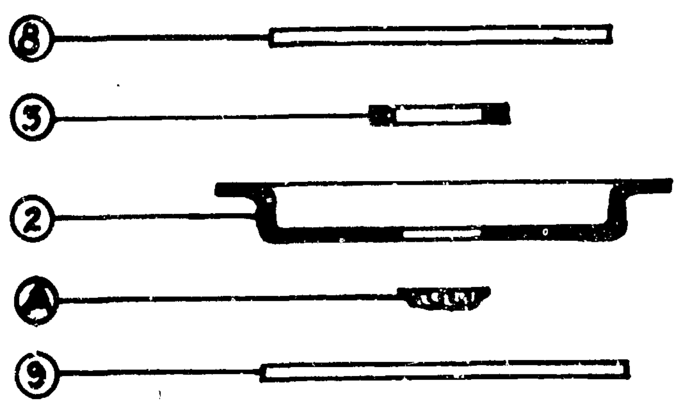
Magnesium "V" Wafer Cell



1. Conductive Intercell
2. Cell Wrap
3. Adhesive ring (seal)
4. Conductive Carbon Collector
5. Cathode Mix
6. Separator
7. Nonpermeable Dot
8. Anode (Magnesium)
9. Metallic Moisture Barrier

Figure 2

Magnesium "V" Wafer Cell



8. Anode (Magnesium)

3. Adhesive ring (seal)

2. Cell Wrap

A. Conductive Contact Material

9. Metallic Moisture Barrier

Figure 3

FIG. 4

ROLLED CAN SEAM

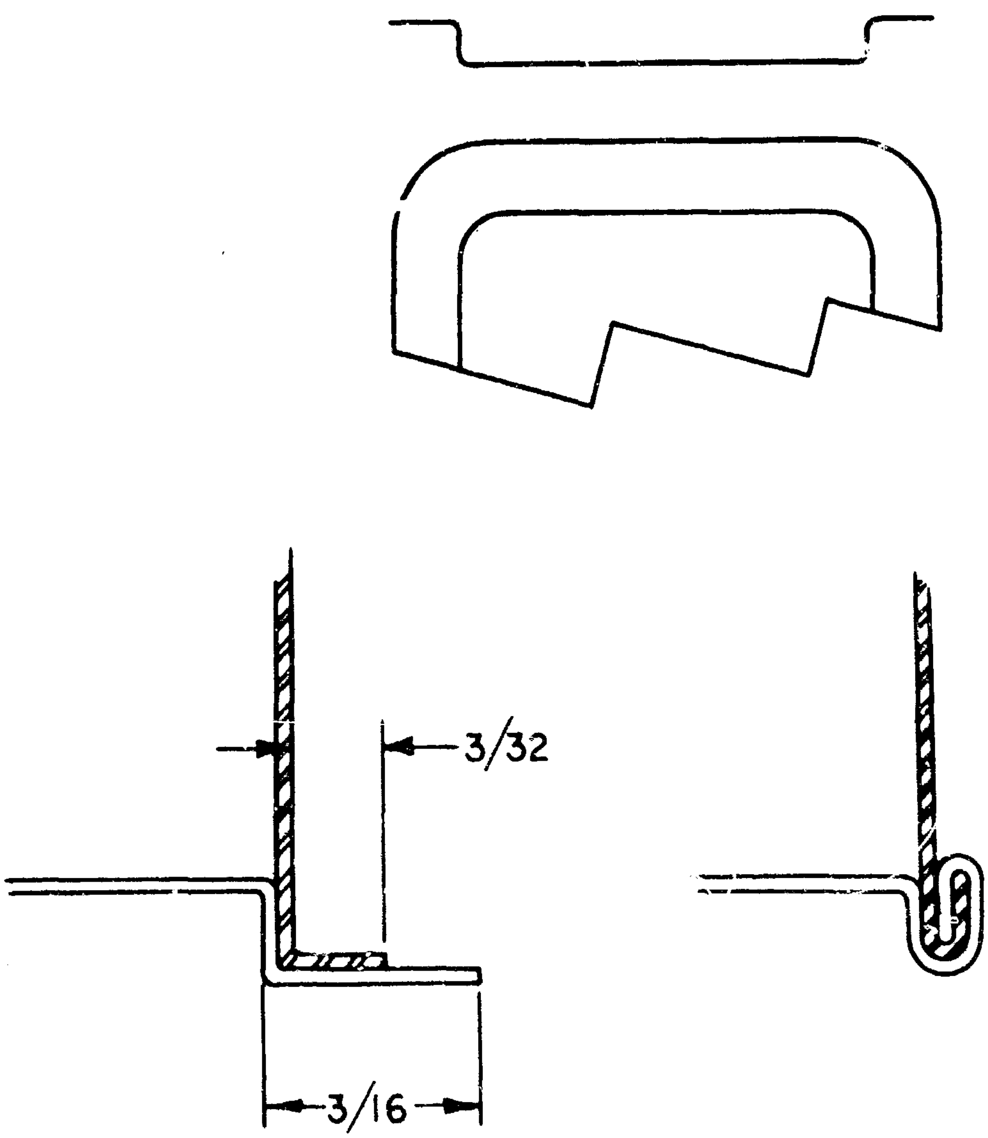
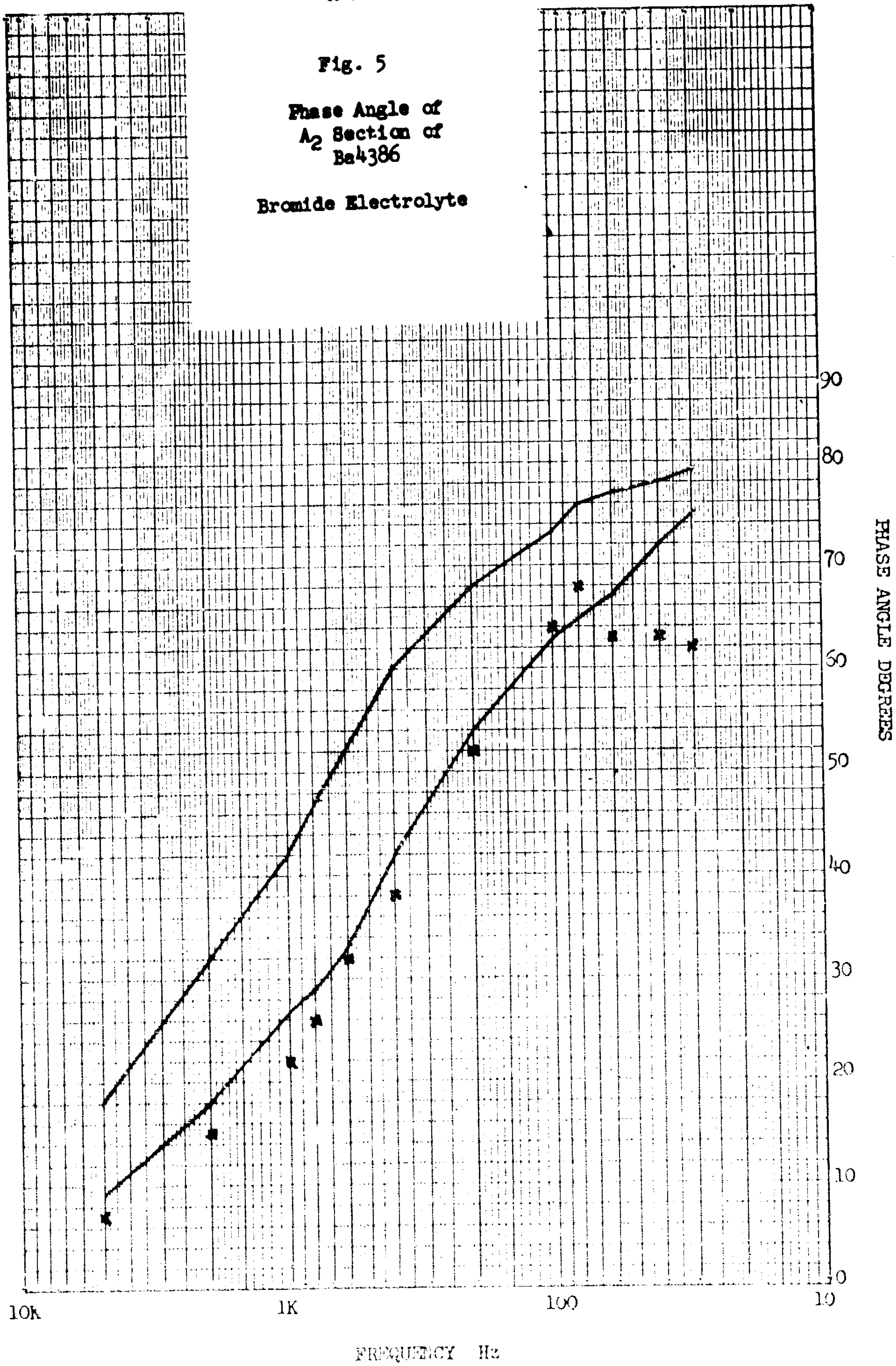


Fig. 5

Phase Angle of A_2 Section of Ba4386

Bromide Electrolyte



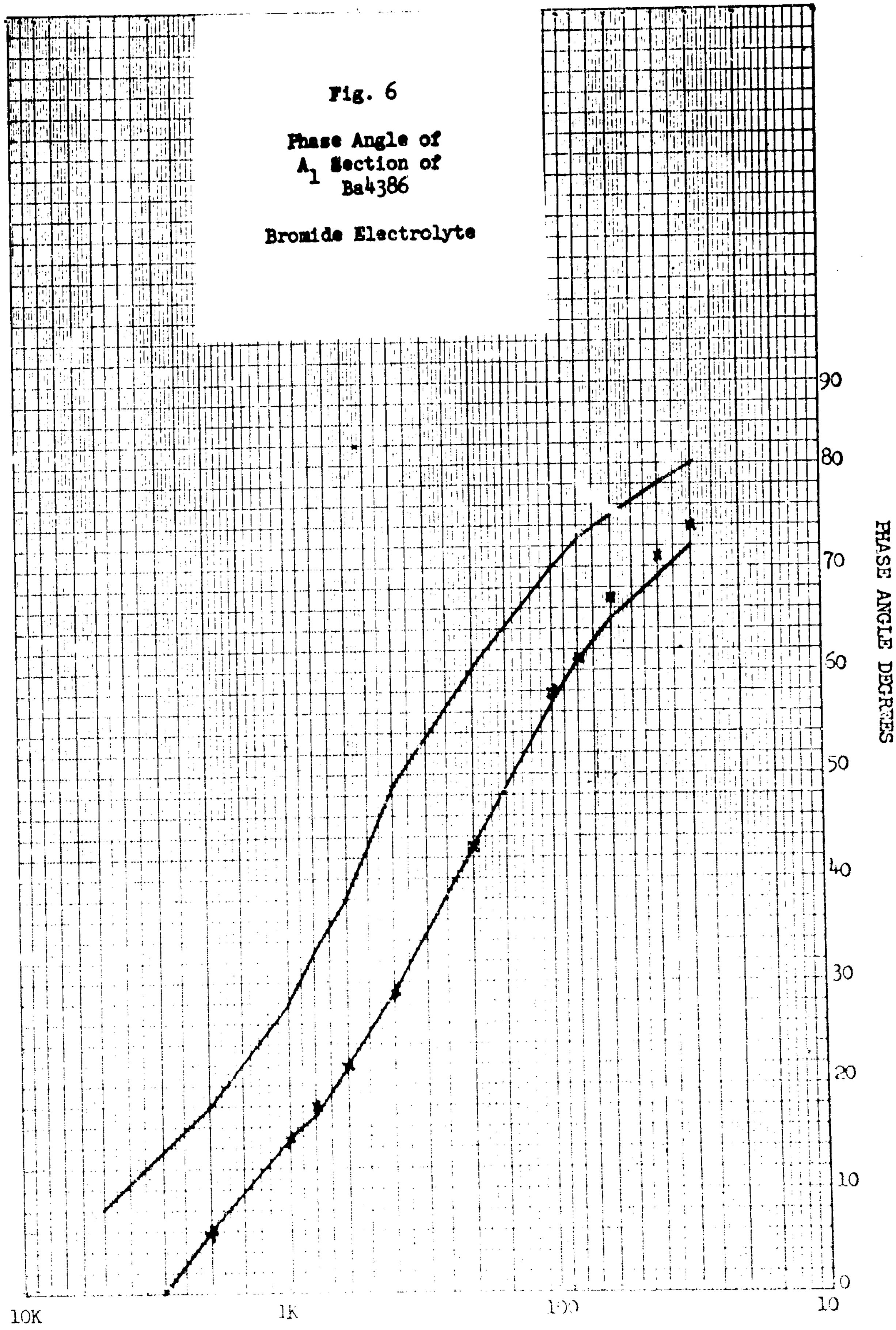


Fig. 6

Phase Angle of A_1 Section of Ba4386

Bromide Electrolyte

Fig. 7

Phase Angle of A_2 Section
Units 3, 7, 8, 9, 10 of
Series 5, Table XI

1 Mo. @ 160°F.

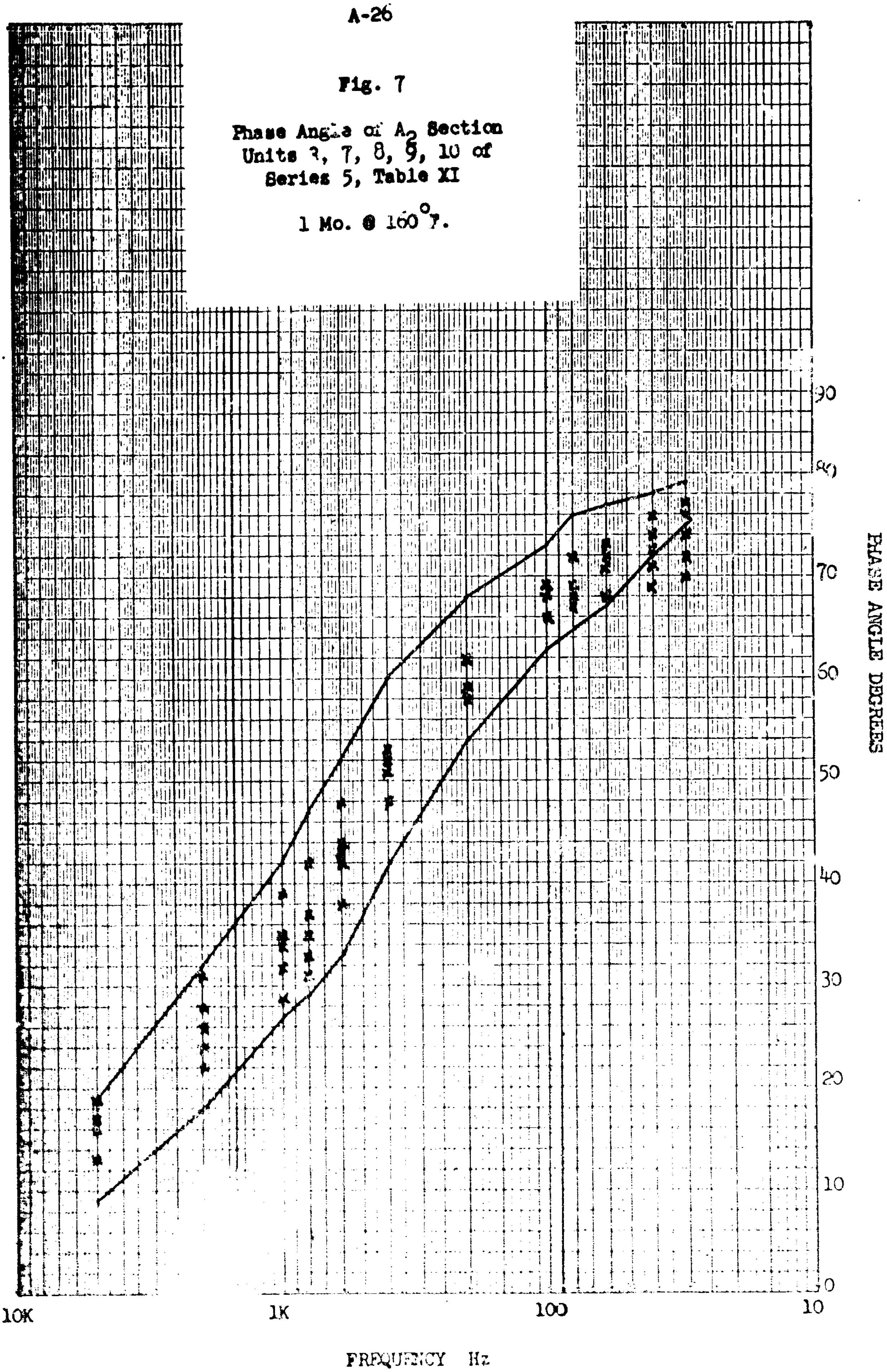


Fig. 8

Phase Angle of A_1 Section
Units 3, 7, 8, 9, 10 of
Series 5, Table XI

1 Mo. @ 160°F.

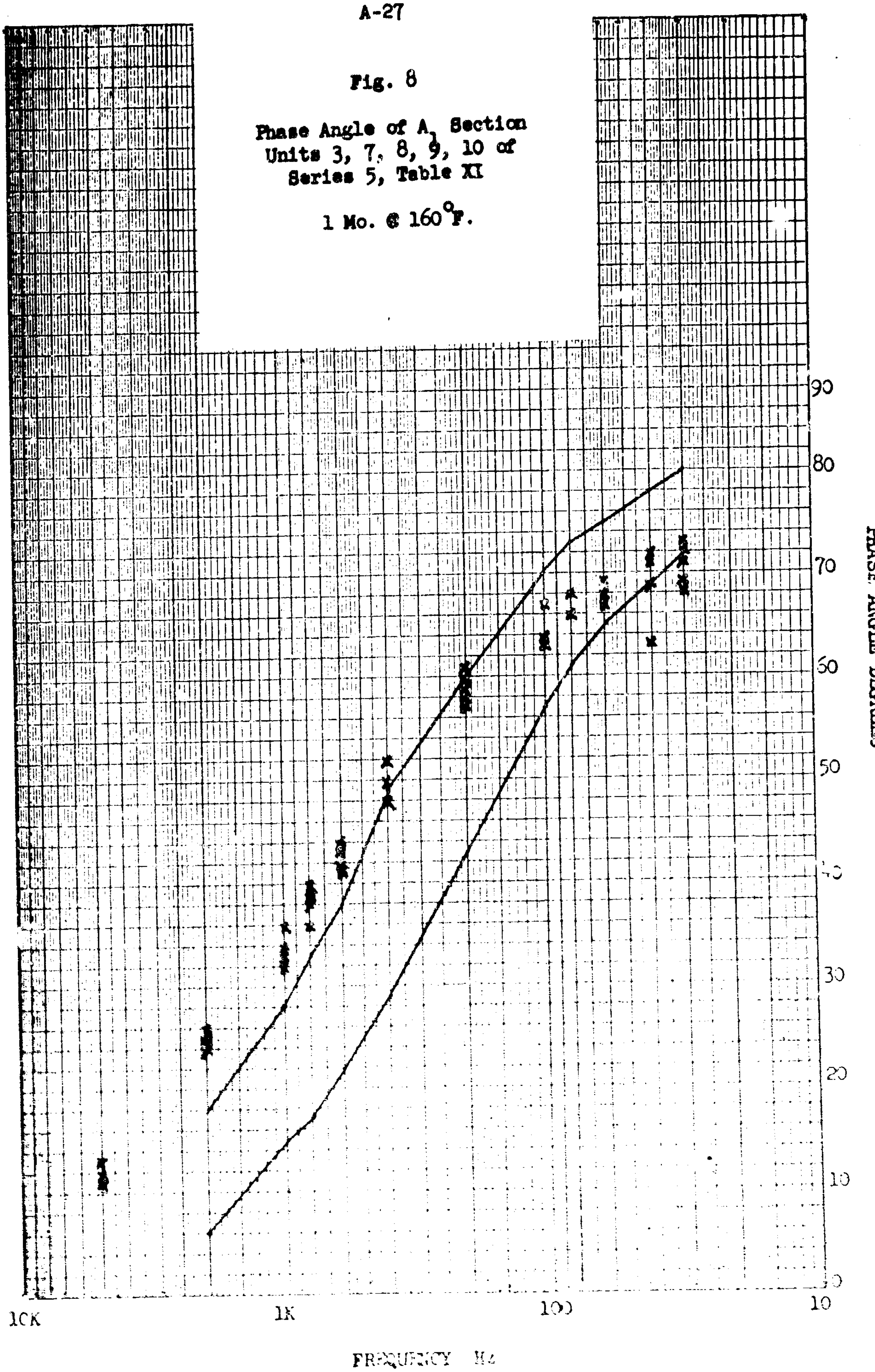
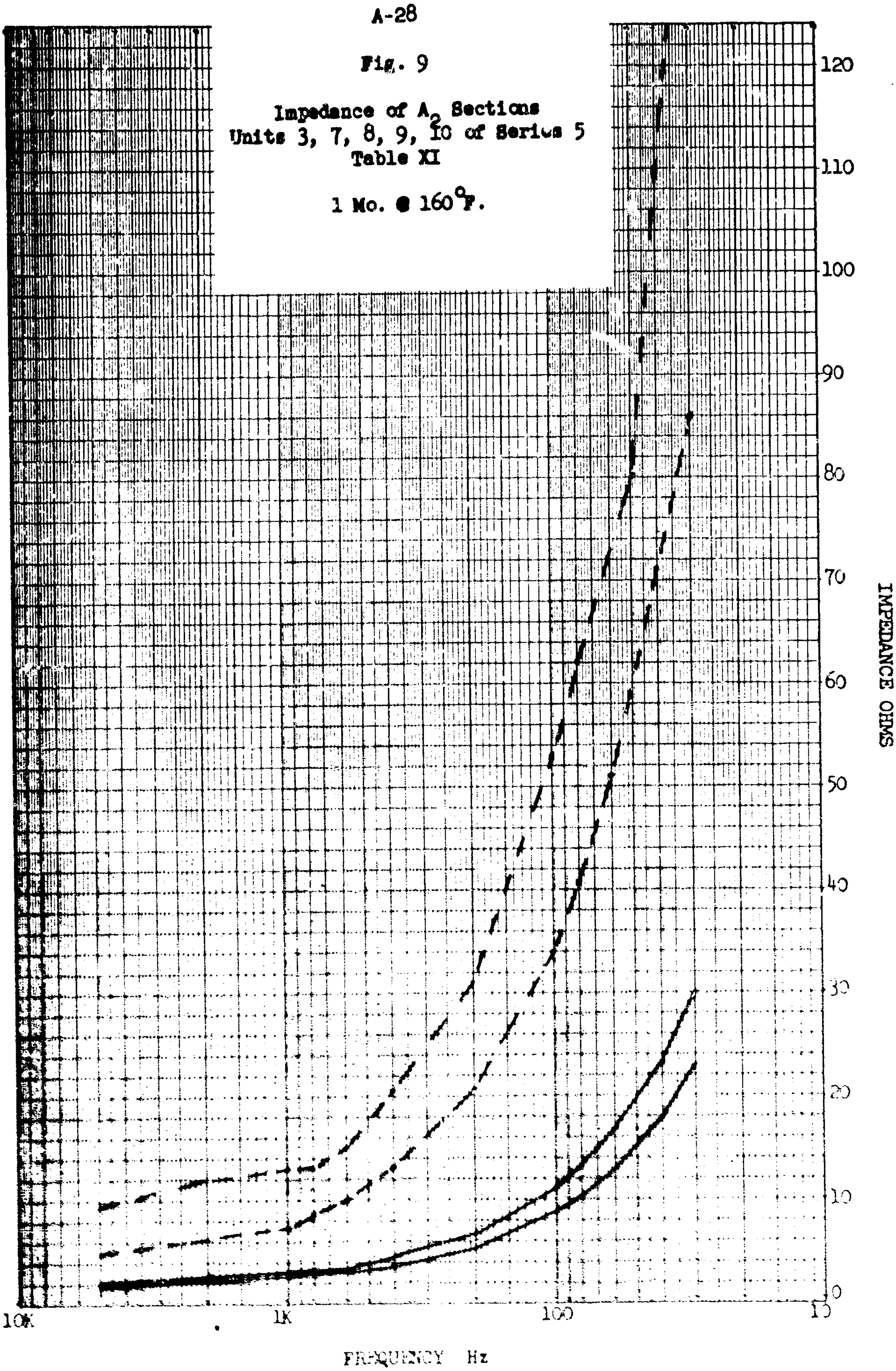


Fig. 9

Impedance of A_2 Sections
Units 3, 7, 8, 9, 10 of Series 5
Table XI

1 Mo. @ 160°F.



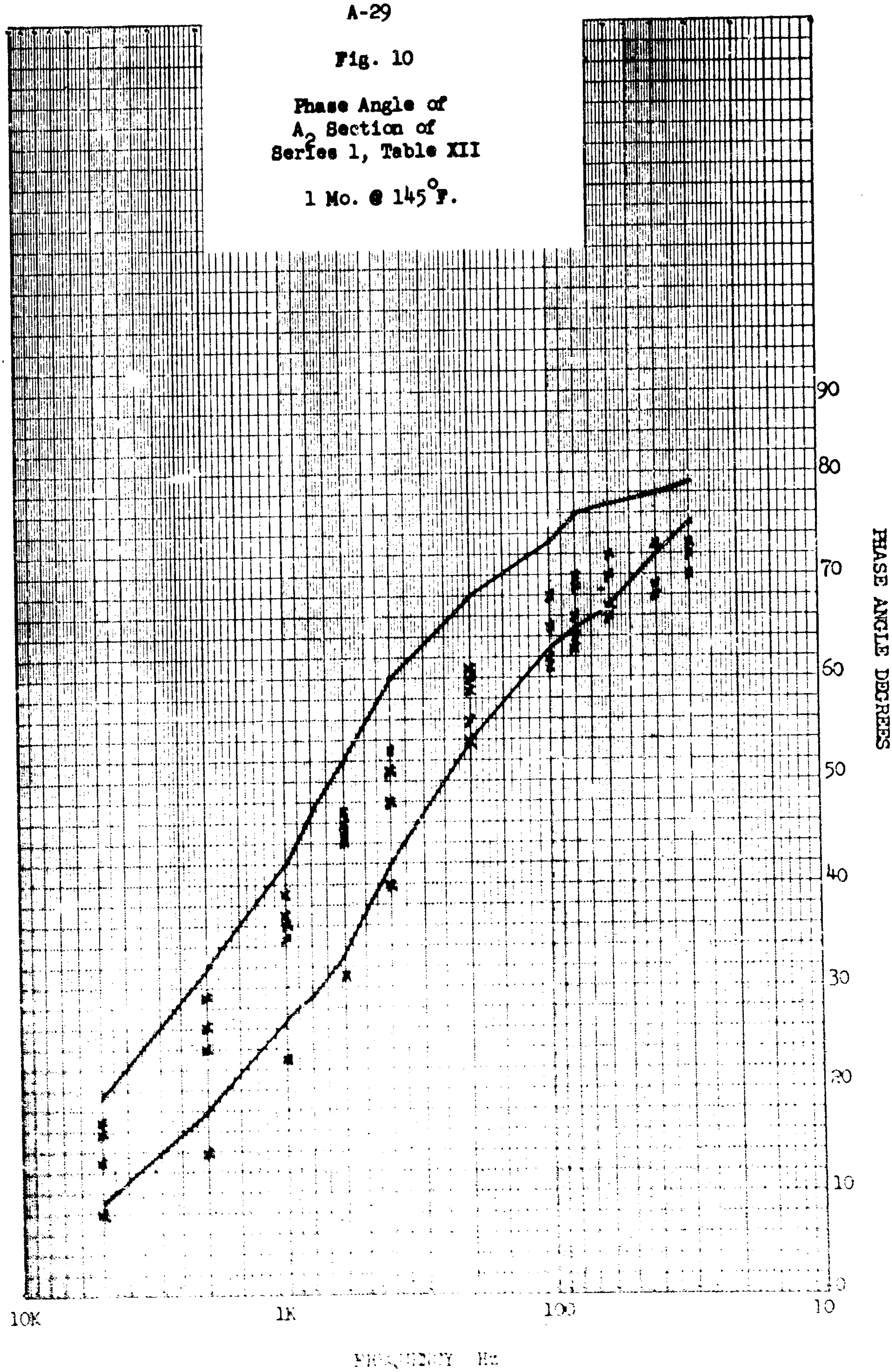


Fig. 10
Phase Angle of
A_2 Section of
Series 1, Table XII
1 Mo. @ 145°F.
90
80
70
60
50
40
30
20
10
0
PHASE ANGLE DEGREES
10K
1K
100
10
FREQUENCY Hz

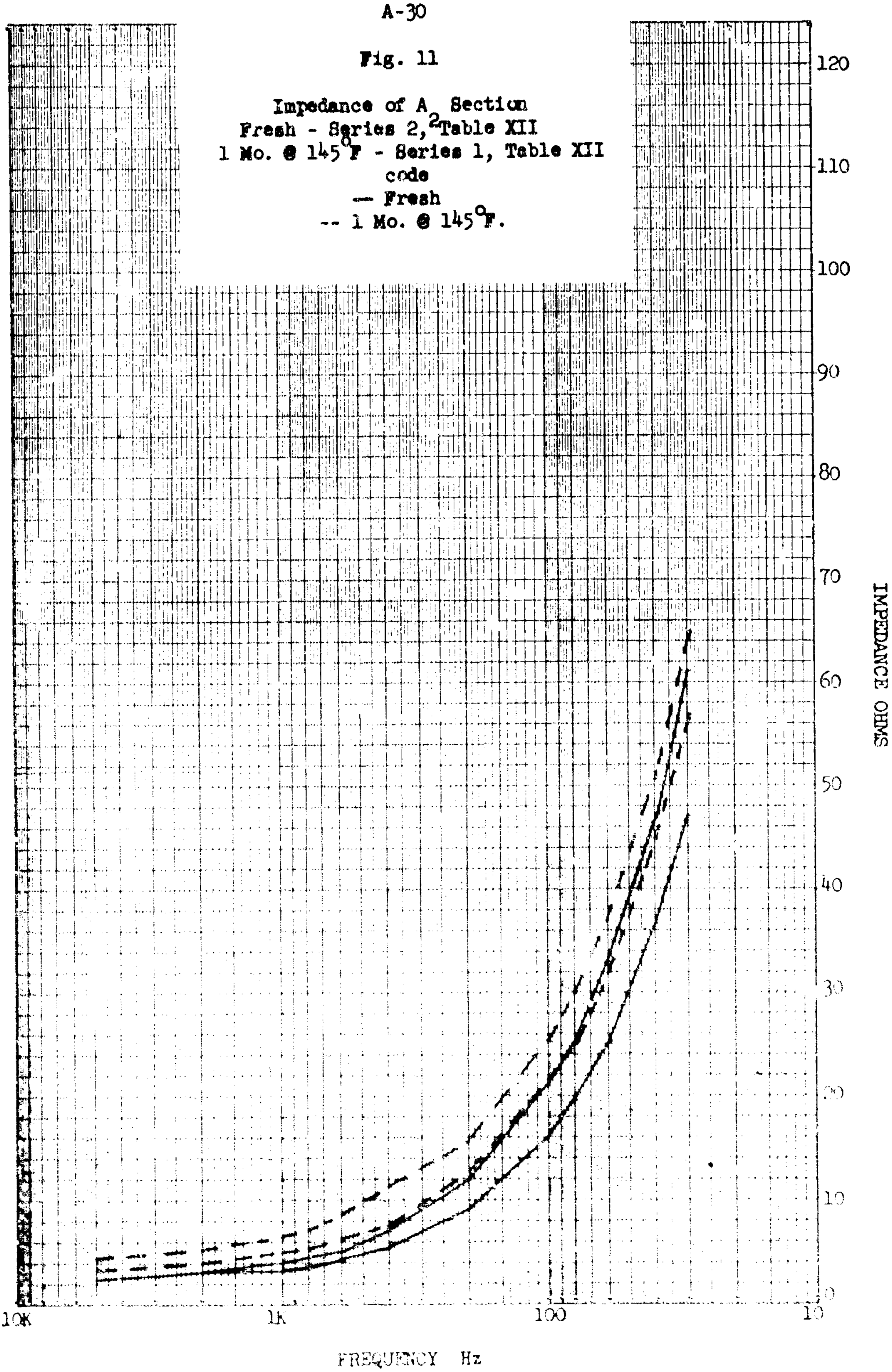


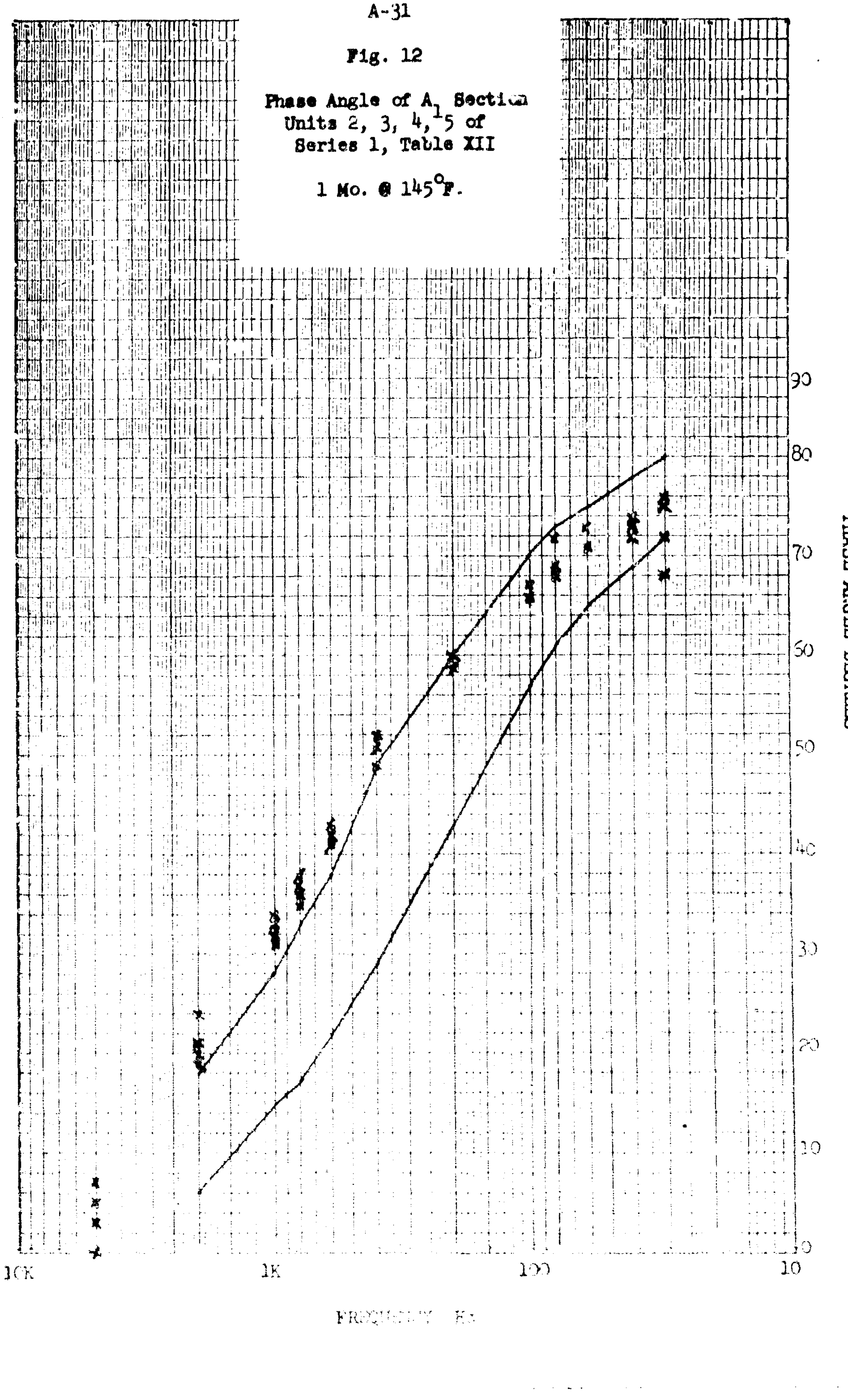
Fig. 11

Impedance of A_2 Section
Fresh - Series 2, Table XII
1 Mo. @ 145°F - Series 1, Table XII
code
— Fresh
-- 1 Mo. @ 145°F.

Fig. 12

Phase Angle of A_1 Section
Units 2, 3, 4, 5 of
Series 1, Table XII

1 Mo. @ 145°F.



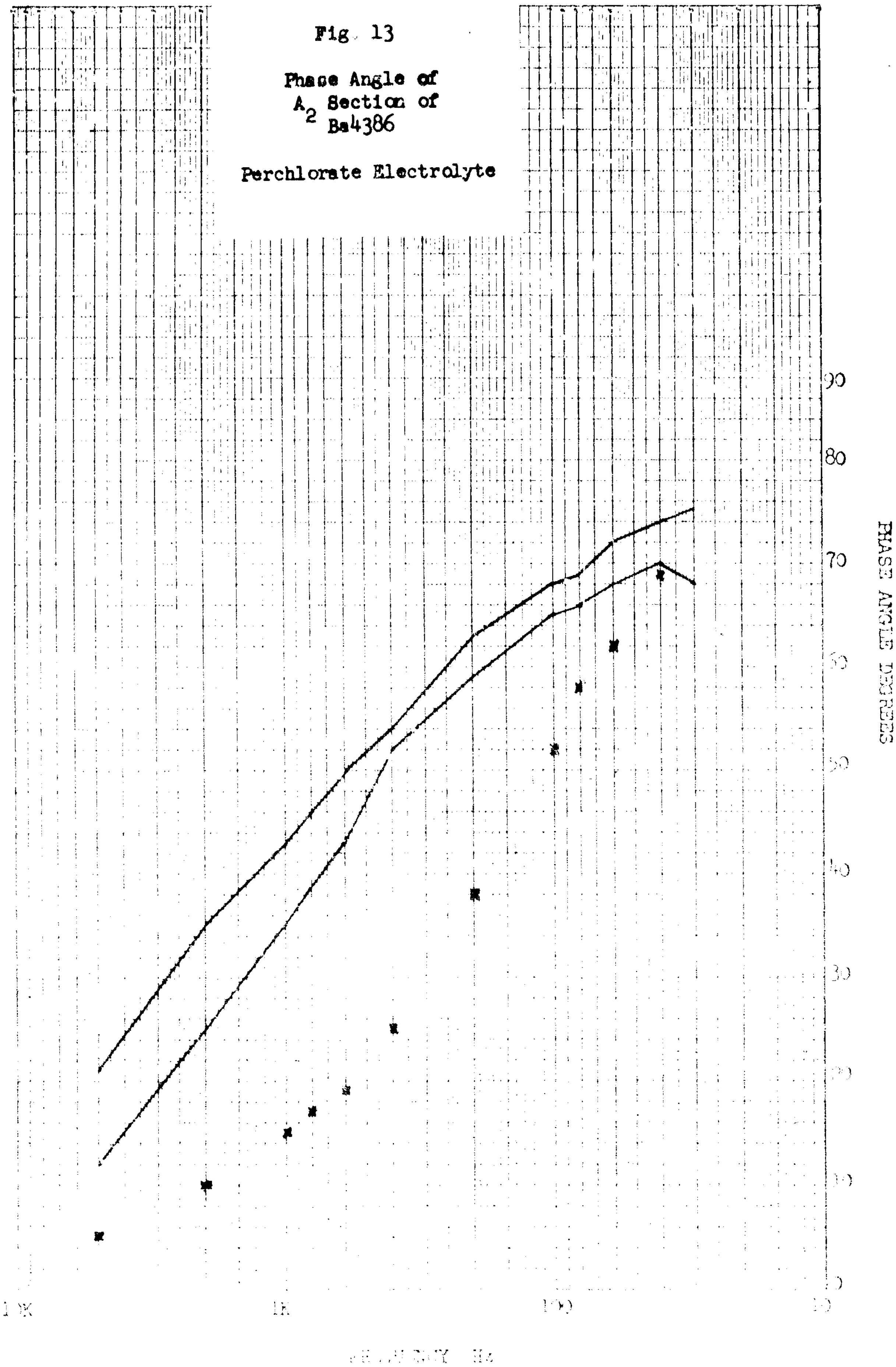


Fig. 13

Phase Angle of A_2 Section of Ba4386

Perchlorate Electrolyte

Fig. 14

Phase Angle of A_1 Section of Ba4386

Perchlorate Electrolyte

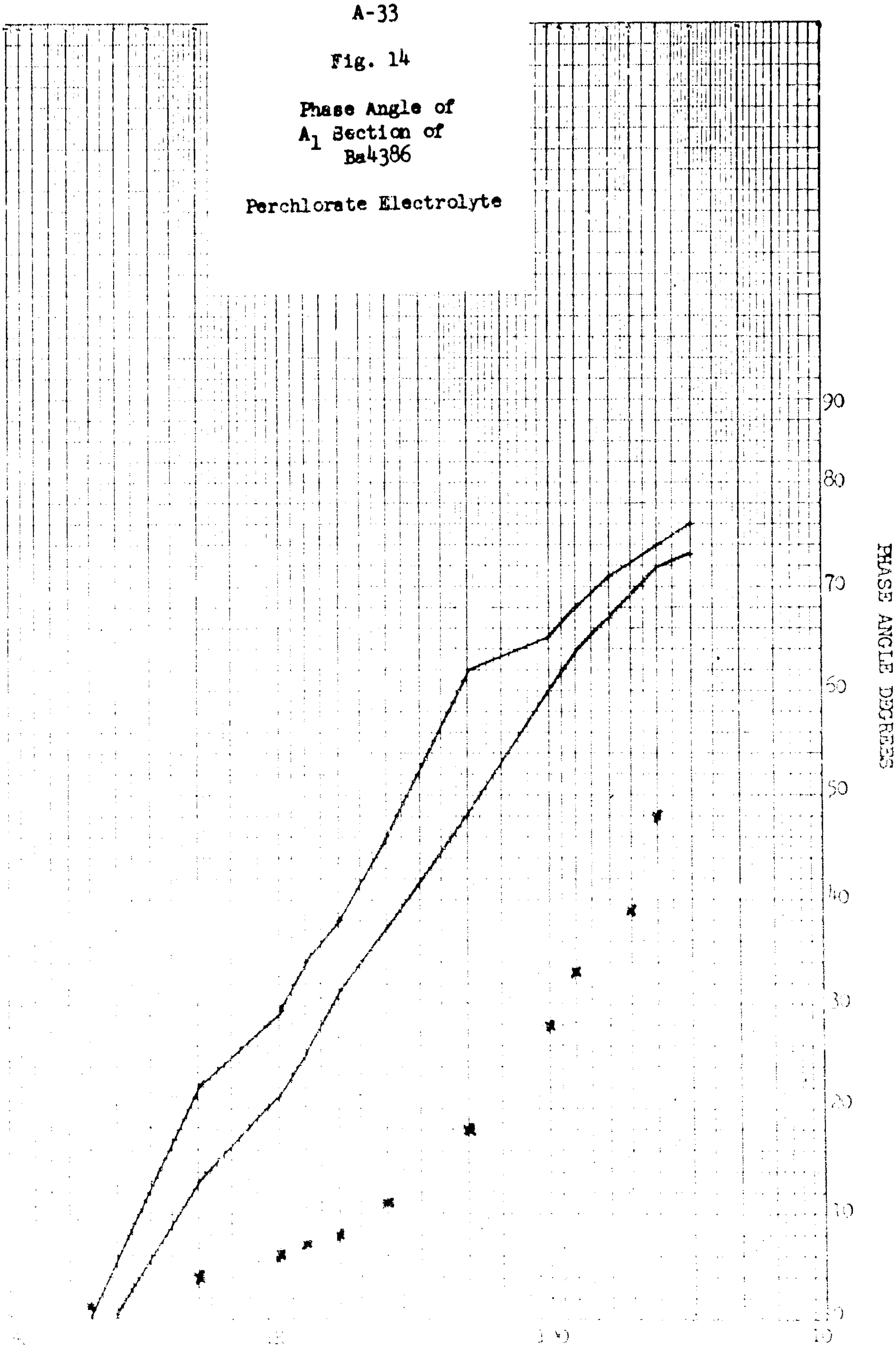


Fig. 15

Phase Angle of
A_2 Section of
Series 1, Table XVI

1 Mo. @ 160°F.

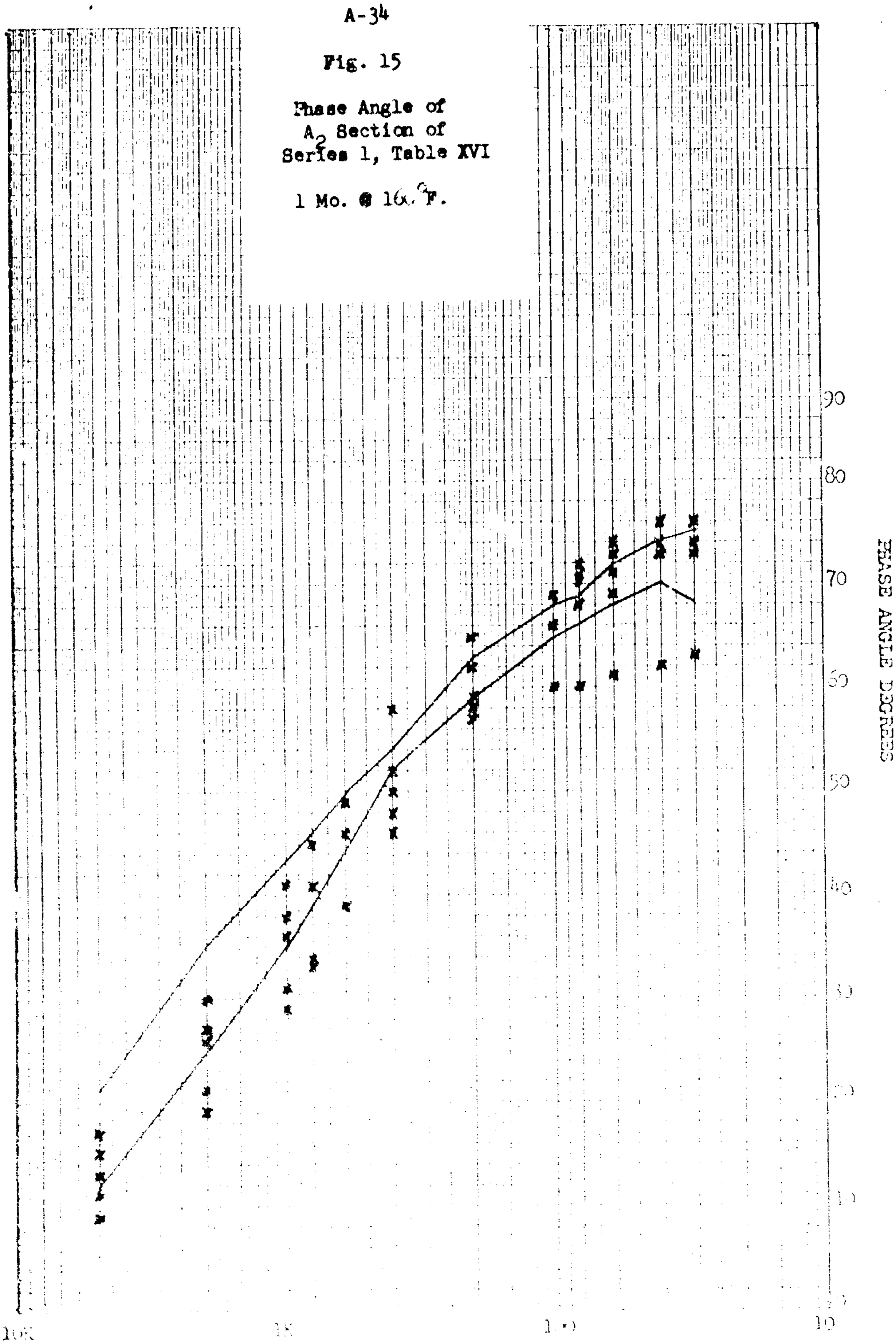
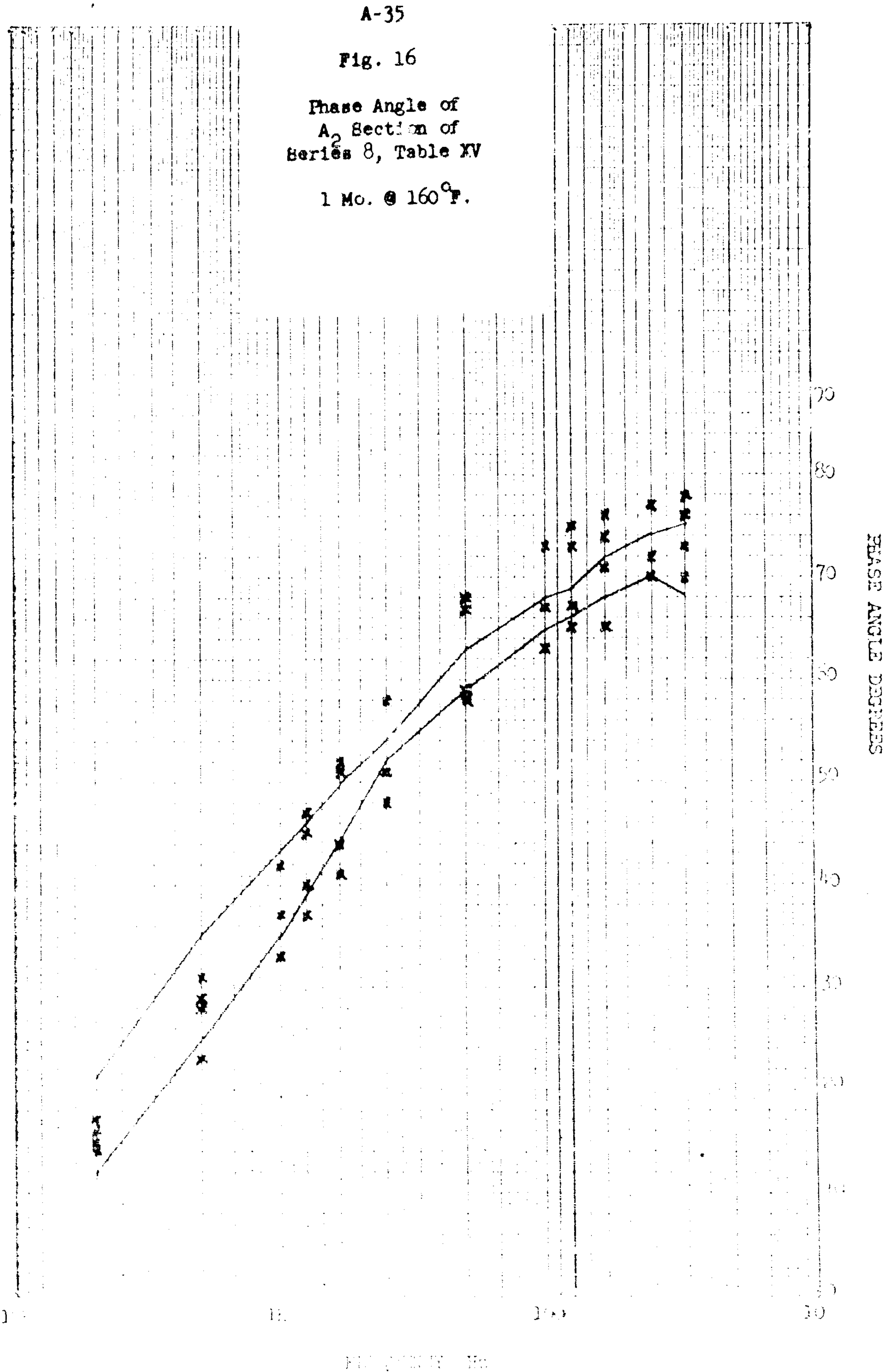


Fig. 16

Phase Angle of A_2 Section of Series 8, Table XV

1 Mo. @ 160°F.



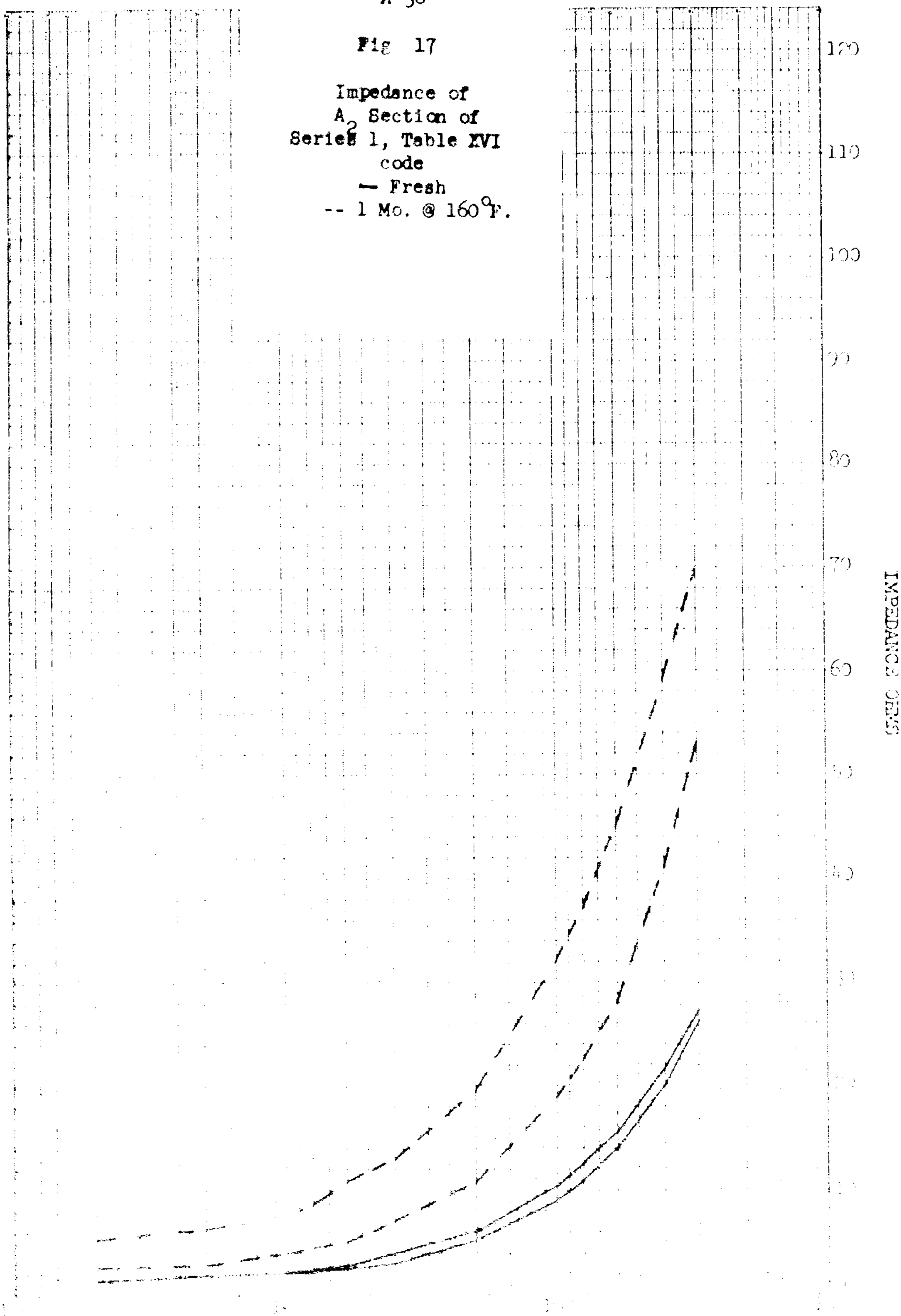


Fig 17

Impedance of A_2 Section of Series 1, Table XVI

code

— Fresh

-- 1 Mo. @ 160°F.

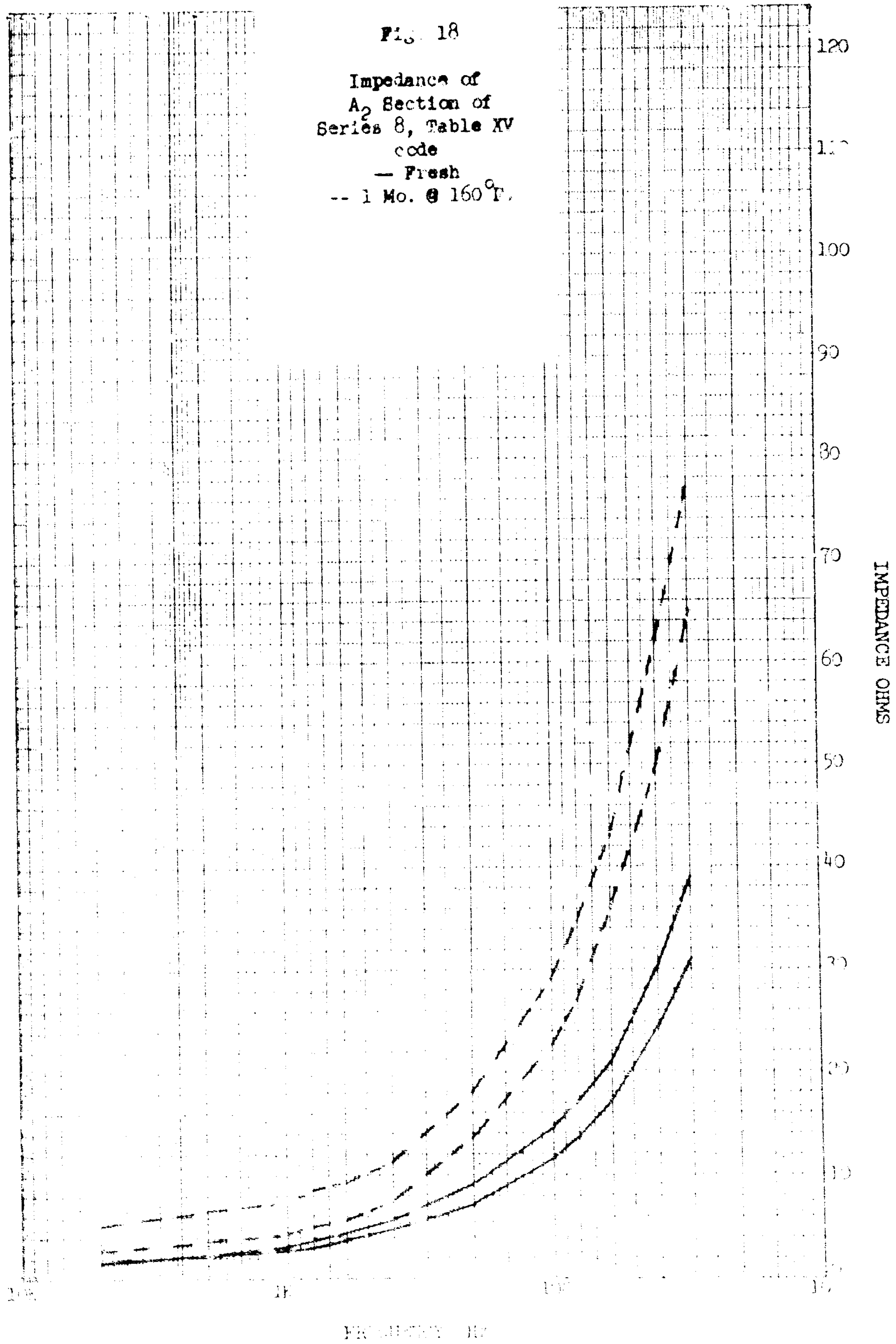


Fig. 18
Impedance of
A_2 Section of
Series 8, Table XV
code
— Fresh
-- 1 Mo. @ 160°F.
120
100
90
80
70
60
50
40
IMPEDANCE OHMS

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13. ABSTRACT

The principal physical condition causing constructional difficulties in both the 1-3/4 X 3-1/4 inch and 1-1/8 X 1-1/8 inch cell size batteries was the evolution of gas during storage and discharge. A revision in seal construction and moisture barrier size reduced the failure rate, particularly on the 1-1/8 X 1-1/8 cell size.

A protective coating to prevent corrosion of the non-reactive side of the anode is necessary to prevent corrosion of the electrical contact area of the anode.

A magnesium wafer battery cannot be contained within a specified dimension due to expansion of discharge products. Provision must be allowed for this expansion in battery design. Special measures to contain the expansion reduces the capacity of the battery.

It should be possible to build a 1-1/8 X 1-1/8 inch cell size battery with a 90% survival rate when stored one month at 160°F.

The Impedance-Phase Angle measurements, particularly phase angle, on complete wafer batteries is a potentially useful method of determining the condition of a battery in a non-destructive manner.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Primary Cells		1				
Magnesium Cells		4				
Magnesium Flat Cells		4				
Magnesium-Magnesium Perchlorate--Manganese Dioxide Cells		4				

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